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ARB's Study of Emissions from "Late-model" Diesel and CNG Heavy-duty Transit Buses: *Preliminary Nanoparticle Measurement Results*

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Global Objectives

- Take “snap-shot” of in-use fleet (not fleet average) and...
- Compare “toxicity” between similar “green” diesel and alternative fuel (CNG) technologies
- Assess duty cycle effects
- Investigate ultrafine (<100nm) emissions

Project Scope

- Testing at ARB's Heavy-duty Vehicle Emissions Laboratory (HDVEL) in Los Angeles
- Three vehicle configurations:
 - CNG without oxidation catalyst
 - Diesel (OEM catalyzed muffler) - BP/ECD-1 (11 ppm S)
 - Diesel (CRT™) - BP/ECD-1 (11 ppm S)
- Five driving schedules + corresponding tunnel blanks:
 - Idle
 - **Steady State+load (55mph, ~60% available power)**
 - **CBD - Central Business District Cycle**
 - UDDS - Urban Dynamometer Driving Cycle
 - NYBC - New York Bus Cycle
- PM samples collected over multiple cycles

Project Scope (cont'd)

- Emissions: TPM, THC/NMHC, NO_x, CO, CO₂ and NO₂
- On-site Analysis for Speciation of Air Toxic HC's
- Carbonyl Compounds
- Phase distribution of PAH's
- PM extractions for Ames Bioassay
- Elemental Carbon/Organic Carbon Split (TOR)
- Elemental Analysis (XRF)
- Size-segregated mass emissions (MOUDI)
- Particle number and size distribution (2 SMPS's, ELPI)
- Fuel and lube oil analysis

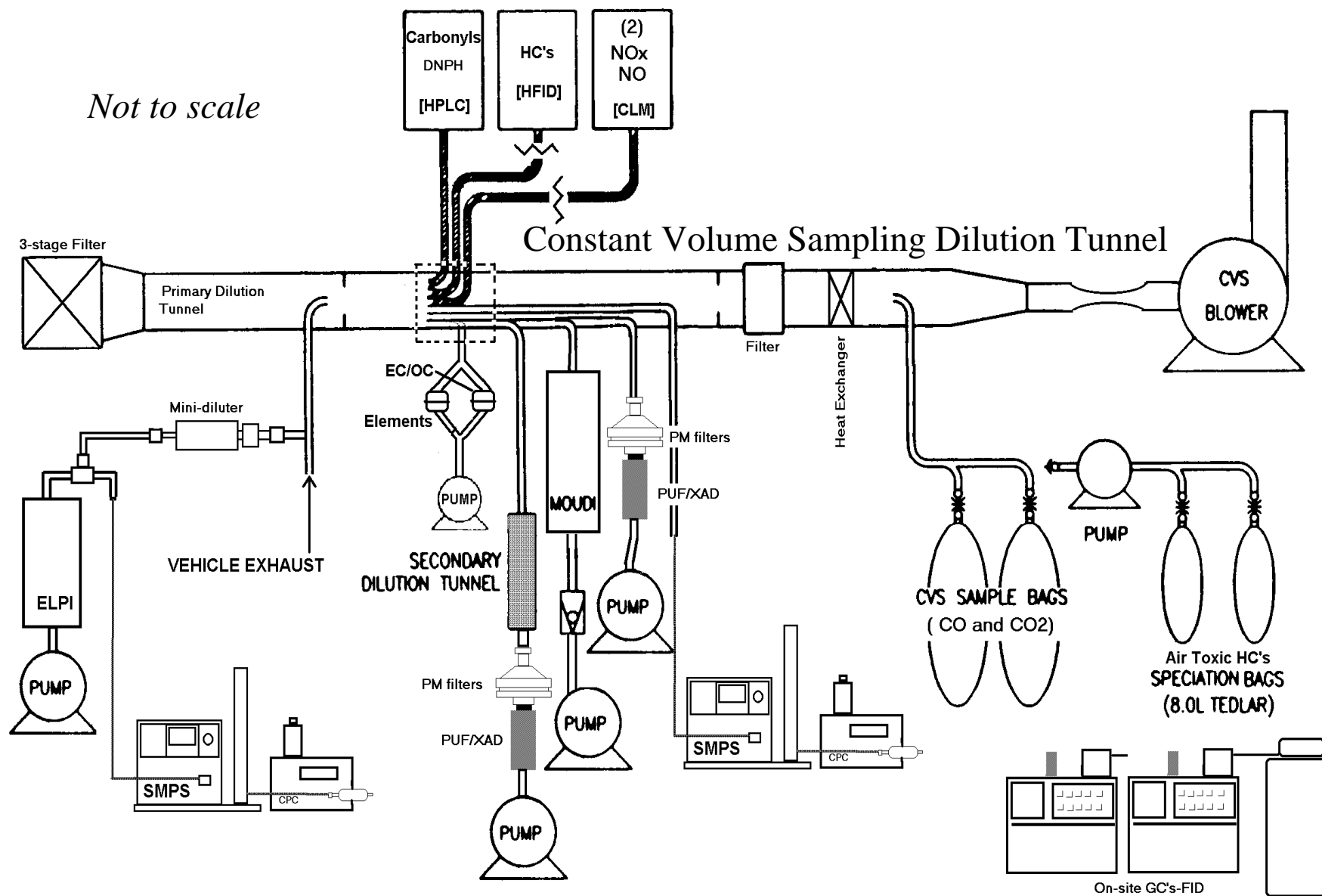
Test Vehicles

	<u>“CNG”</u> <u>“CNG re-test”</u>	<u>“Diesel</u> <u>(OEM)”</u>	<u>“CRT”</u>
<i>Model</i>	2000 DDC Series 50G	1998 DDC Series 50	1998 DDC Series 50
<i>Aftertreatment</i>	None	OEM Catalyzed Muffler	CRT™
<i>Fuel</i>	CNG	ECD-1	ECD-1
<i>Odometer</i>	19,629	15,169	15,569
<i>Weight</i>	33,150 lbs	30,510	30,510

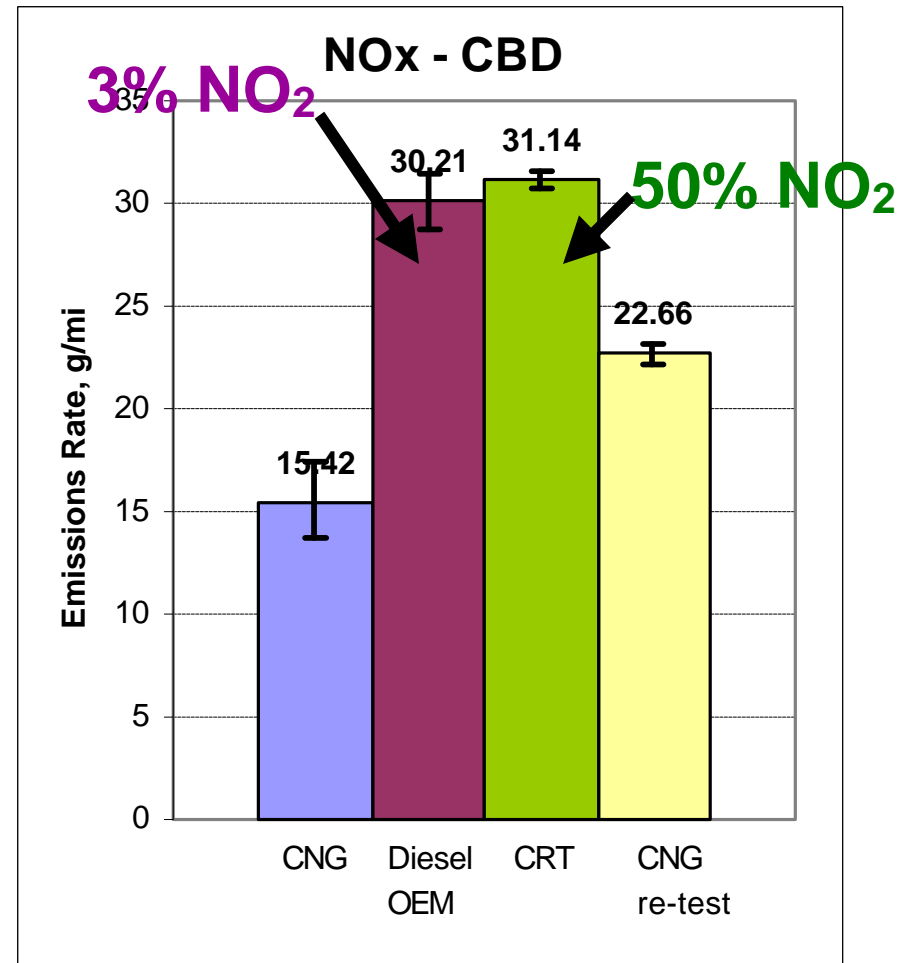
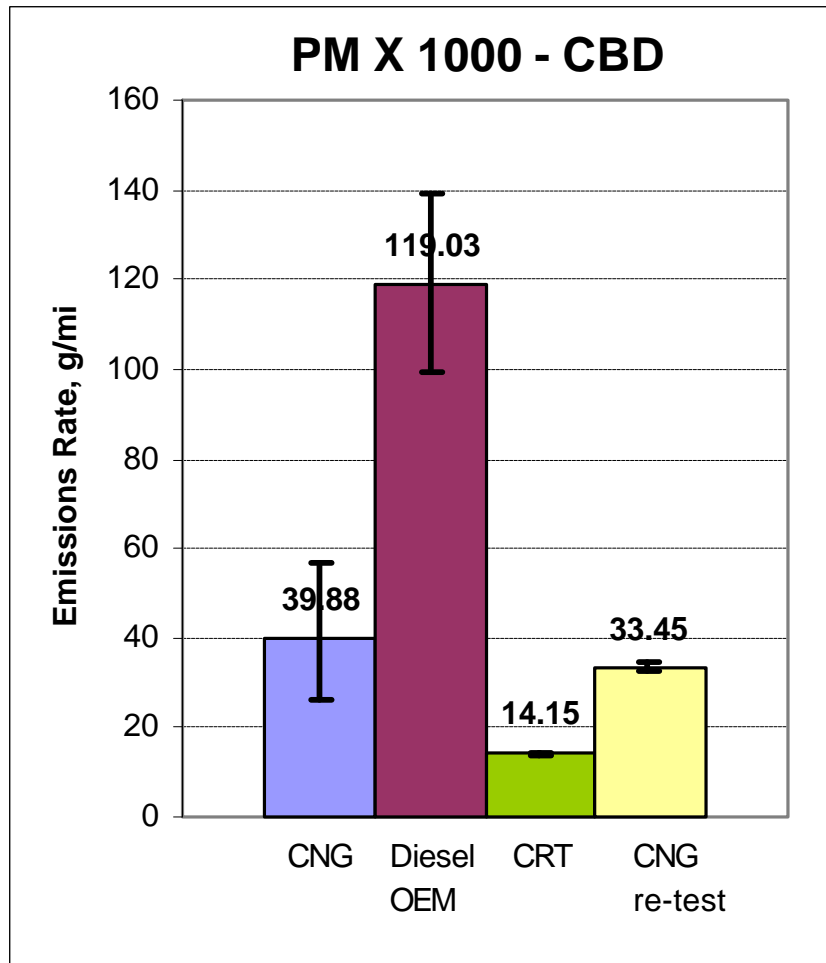
- Los Angeles County Metropolitan Transit Authority fleet
- 8.5 liter, 4-stroke, turbocharged, 4-cylinder, New Flyer Low 40 passenger transit buses

Experimental Setup

Not to scale

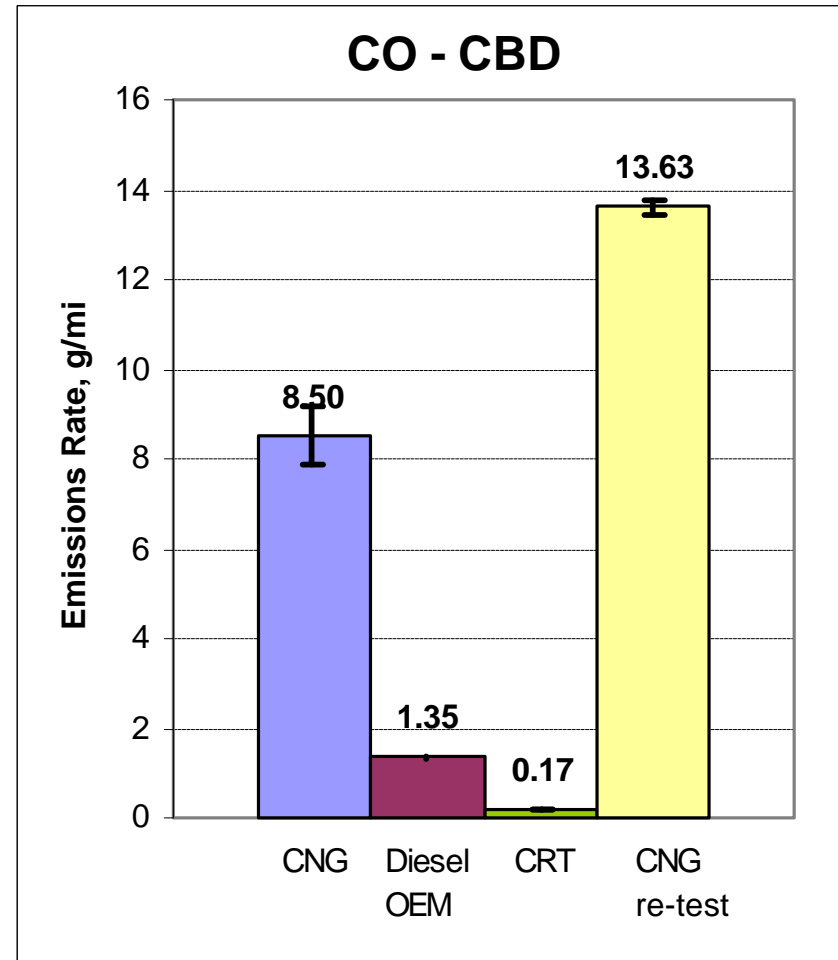
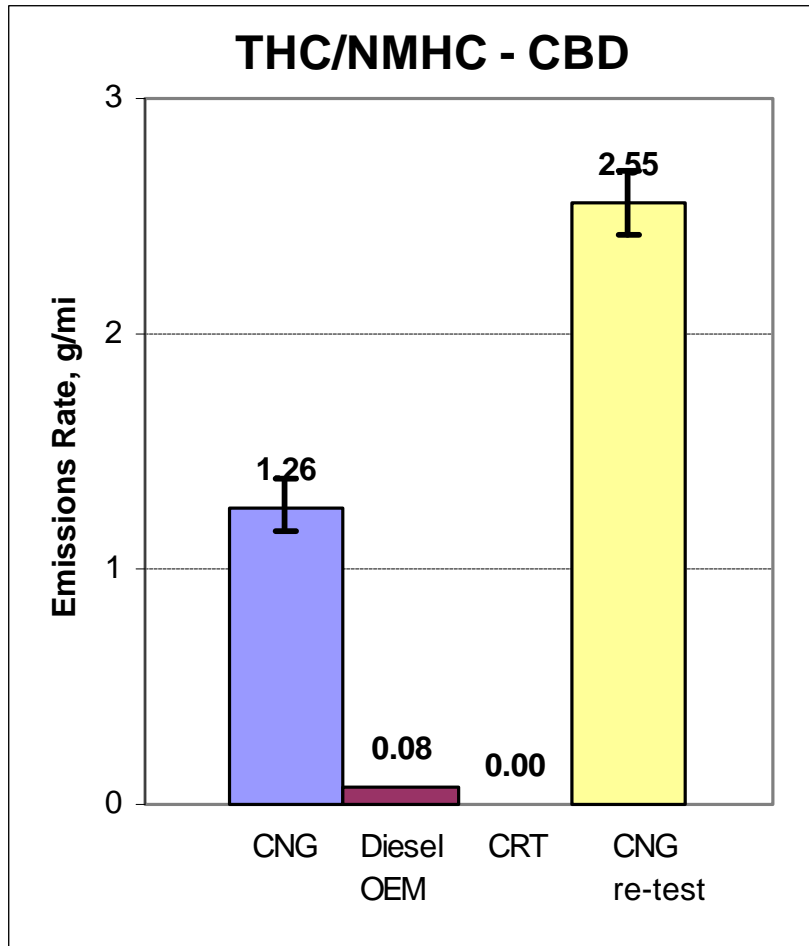


Average NO_x and Raw PM Emissions-CBD



- Note:**
- 1] CRT mass emissions were comparable to background levels*
 - 2] PM emissions uncorrected for Tunnel Blanks*
 - 3] CNG engine software upgraded and O₂ sensor module replaced prior to re-test*

Average HC and CO Emissions-CBD



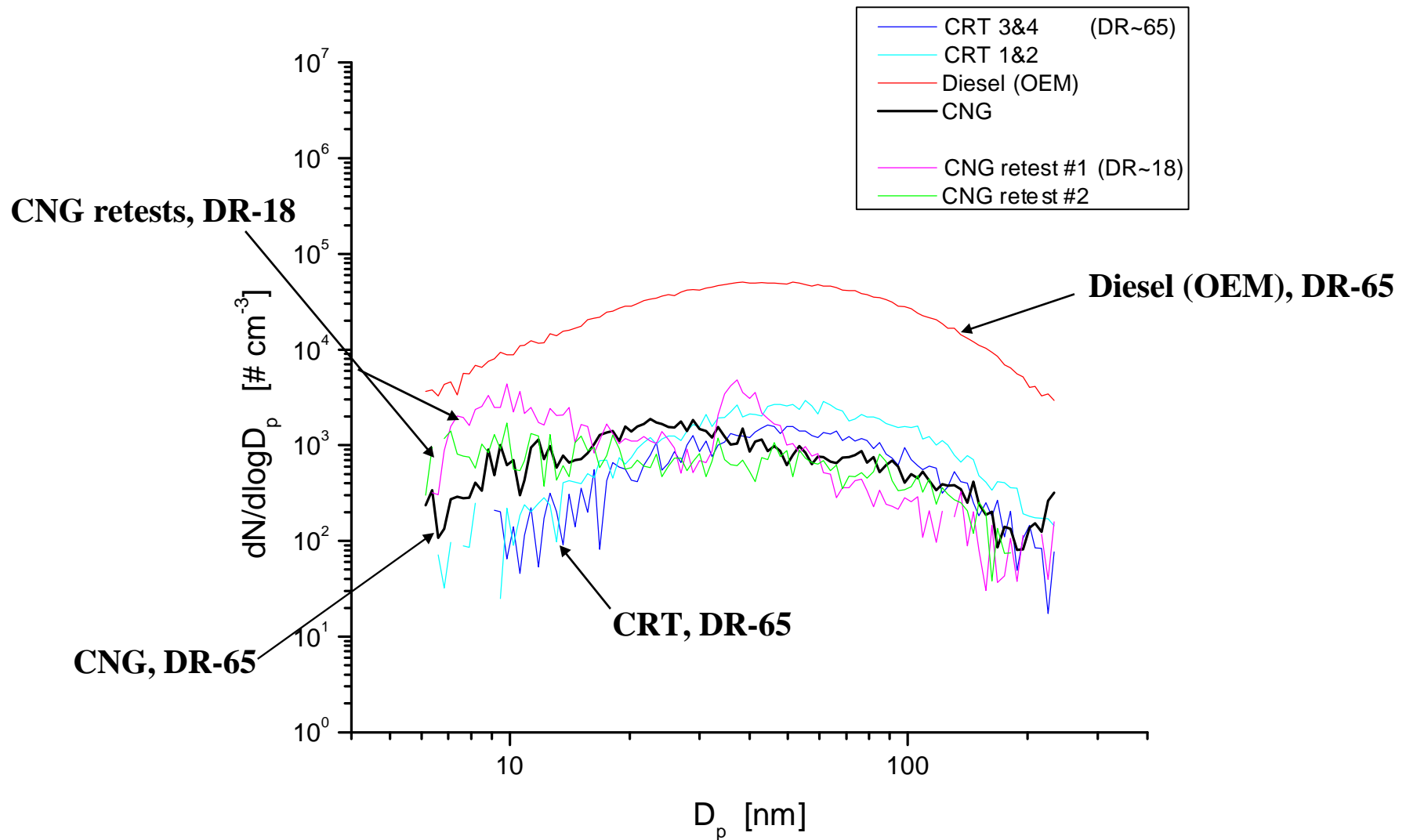
Note: THC for diesel/NMHC for CNG

Ultrafine Particles

- Two SMPS sampling locations/systems:
 - CVS dilution tunnel
 - Raw exhaust single-stage Dekati mini-diluter:
 - Two dilution ratios: ~65 and ~18
 - Oil-free compressor, dessicant/carbon/HEPA-filtered air
 - Aerosol transport lines: residence time ~ 1 to 1.5 sec
- Full scans (**size-scan mode**) for steady state, idle, and tunnel blanks (size range 6 – 237 nm)
- Single diameter real-time recording (**size-filtered mode**) for transient cycles (8, 20, 80, and 140 nm)
- Results shown = actual measured traces uncorrected for dilution or losses

Average of Individual Scans - **Mini-diluter**- SS Tests

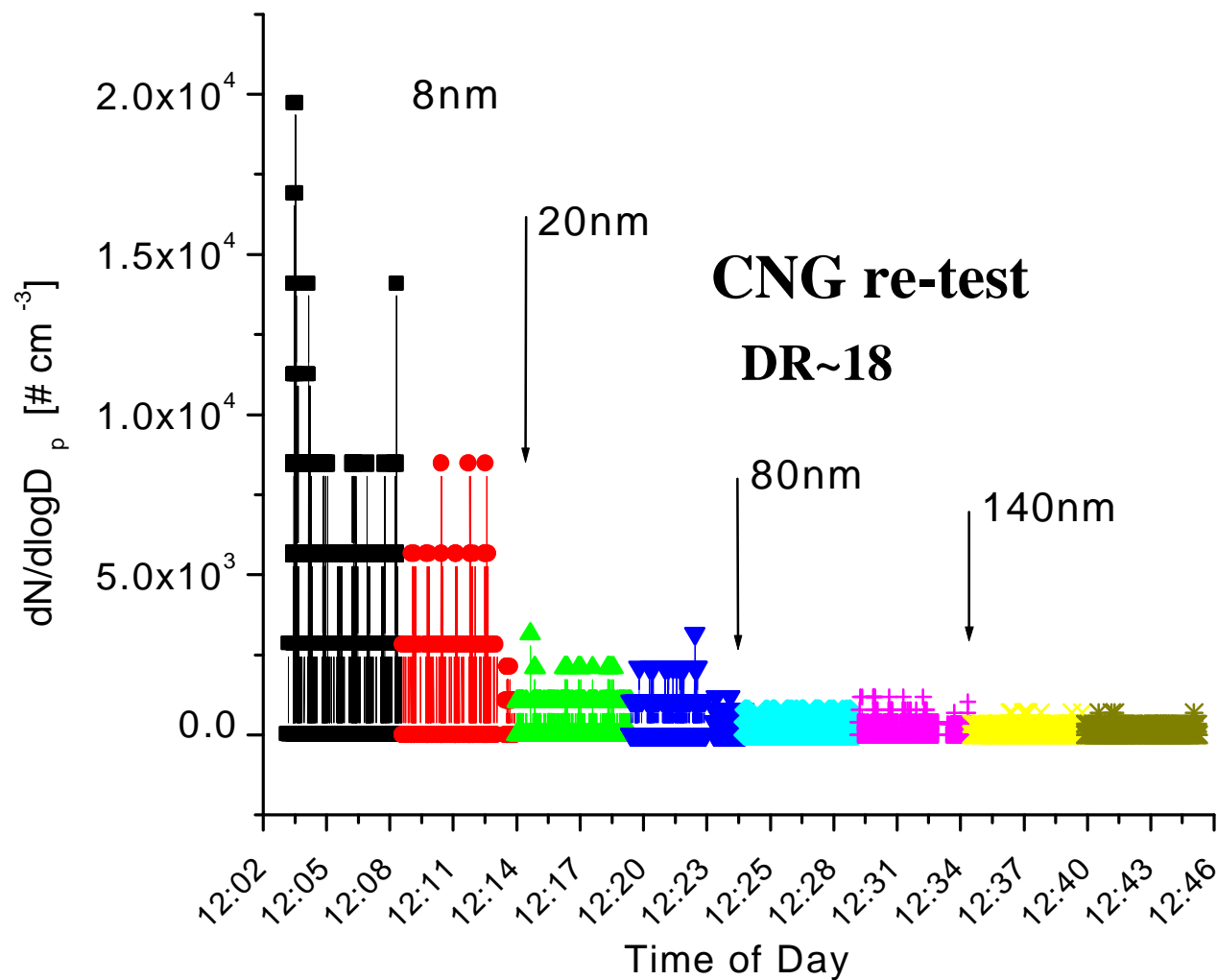
SIZE-SCAN MODE



Note: CNG retest#1 = 55mph, 0% gradient, CNG retest#2=55mph,0.6% gradient

Individual Diameter Traces - Mini-diluter - 4 CBD Cycles

SIZE-FILTERED MODE

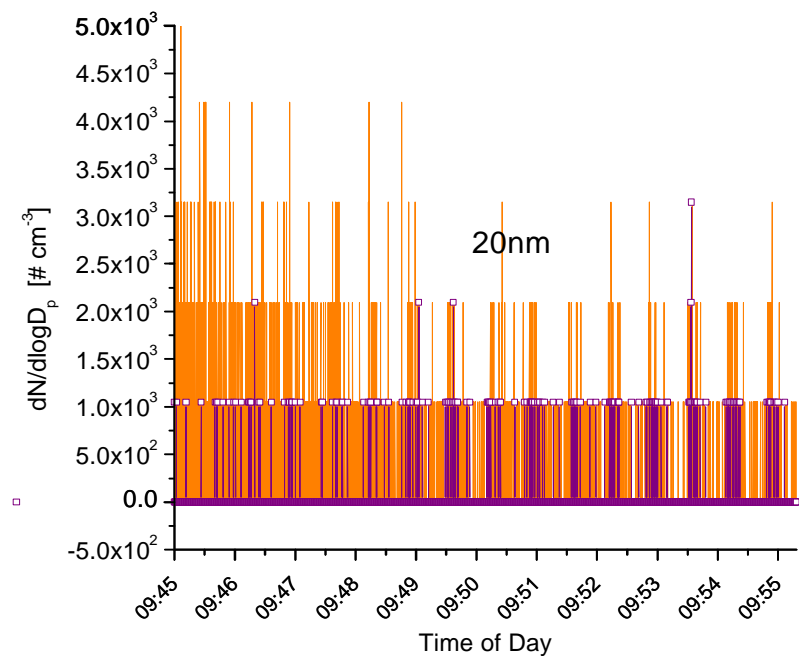
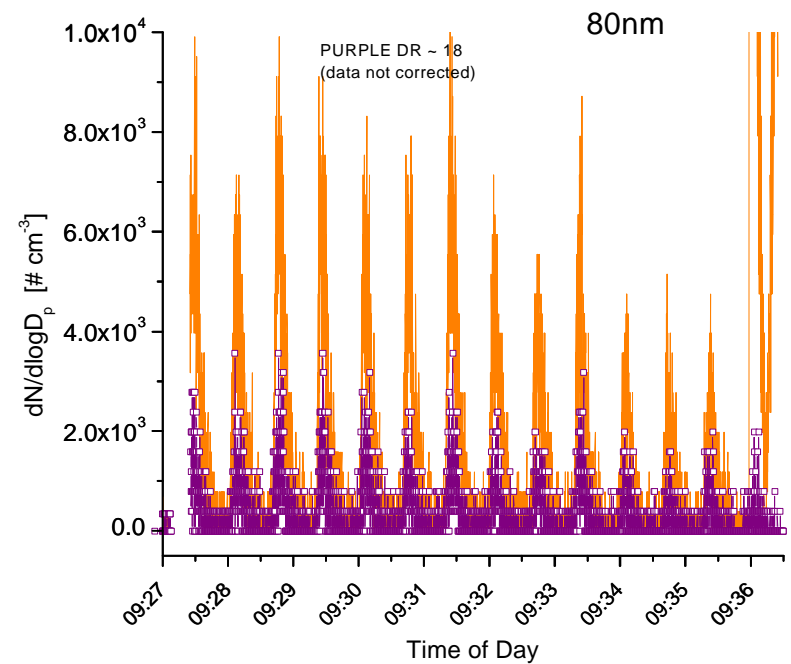
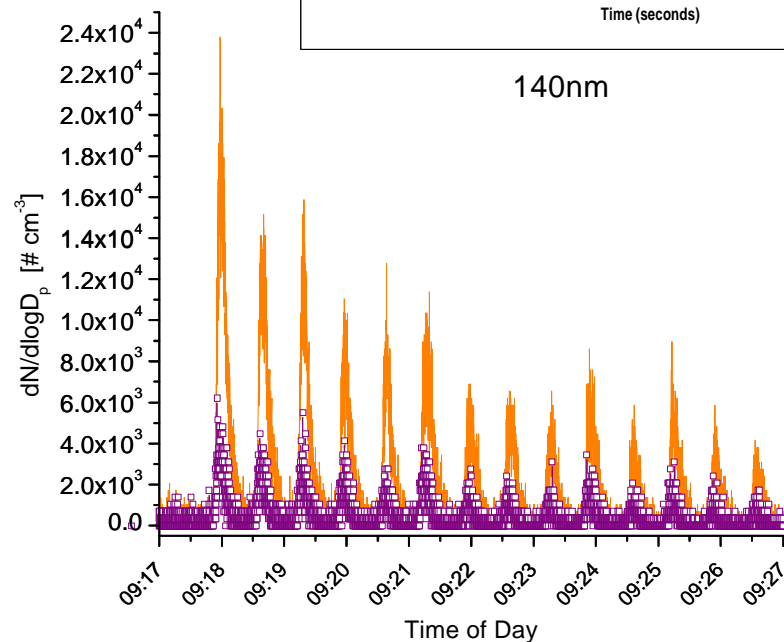
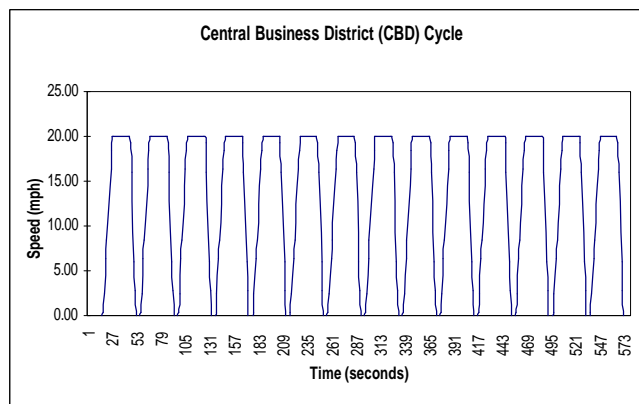


CRT Traces - CBD Tests

SIZE-FILTERED MODE

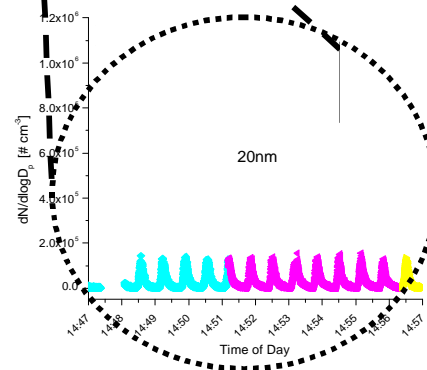
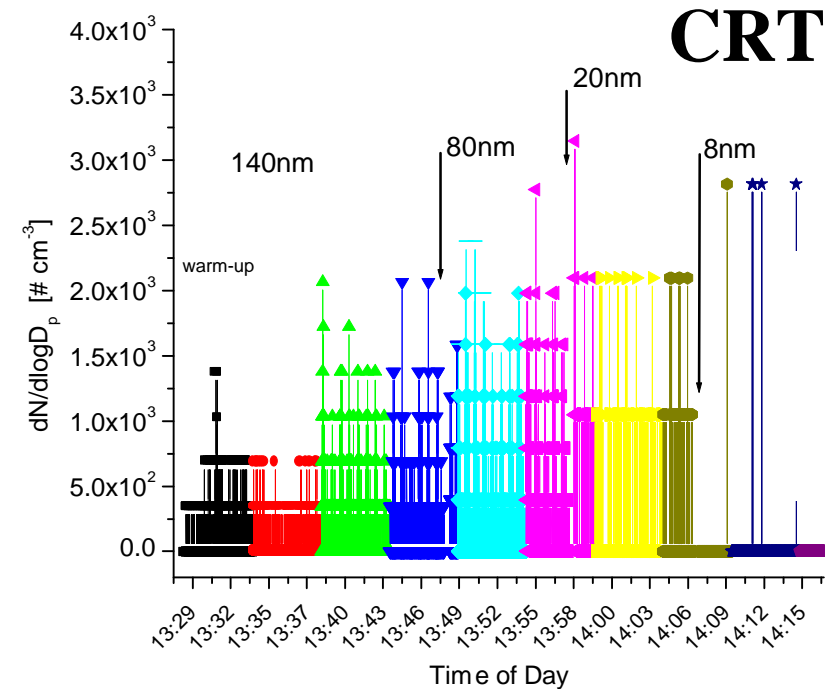
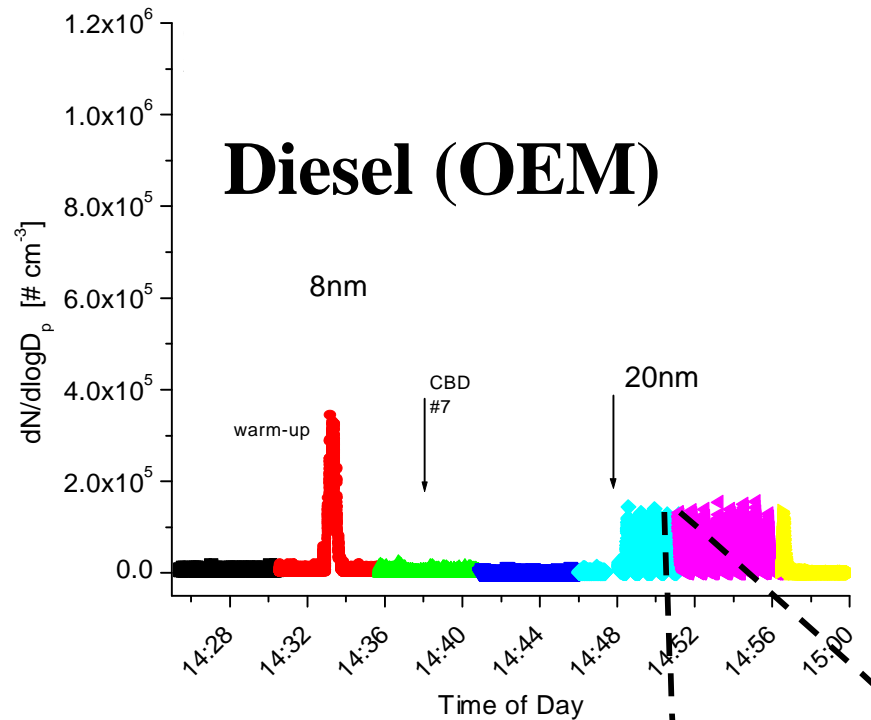
Orange = CVS

Purple = Mini-diluter, DR=18



Individual Diameter Traces - CVS - CBD Tests

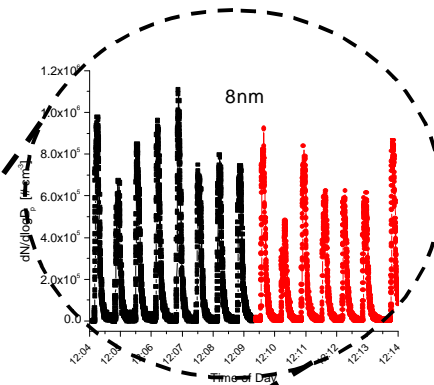
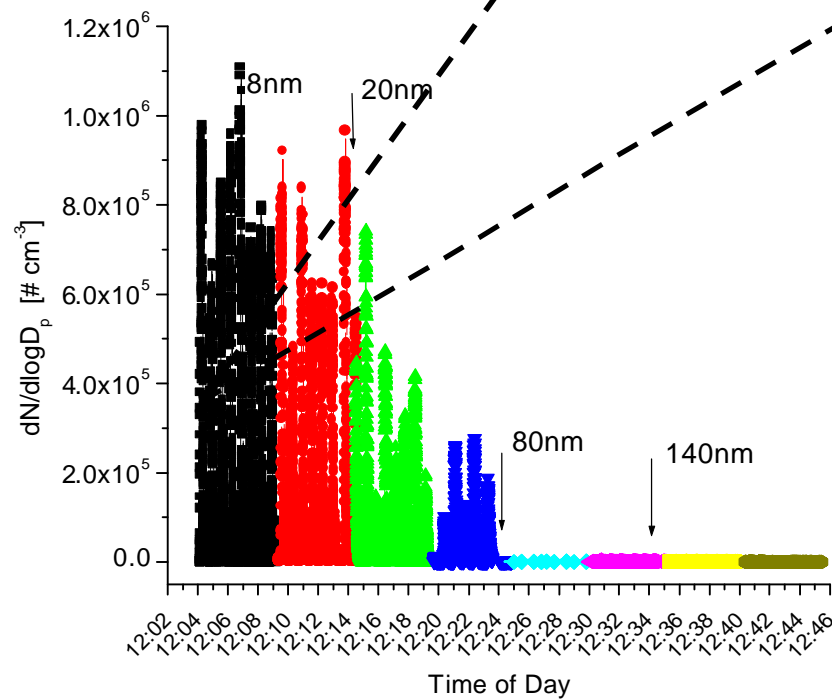
SIZE-FILTERED MODE



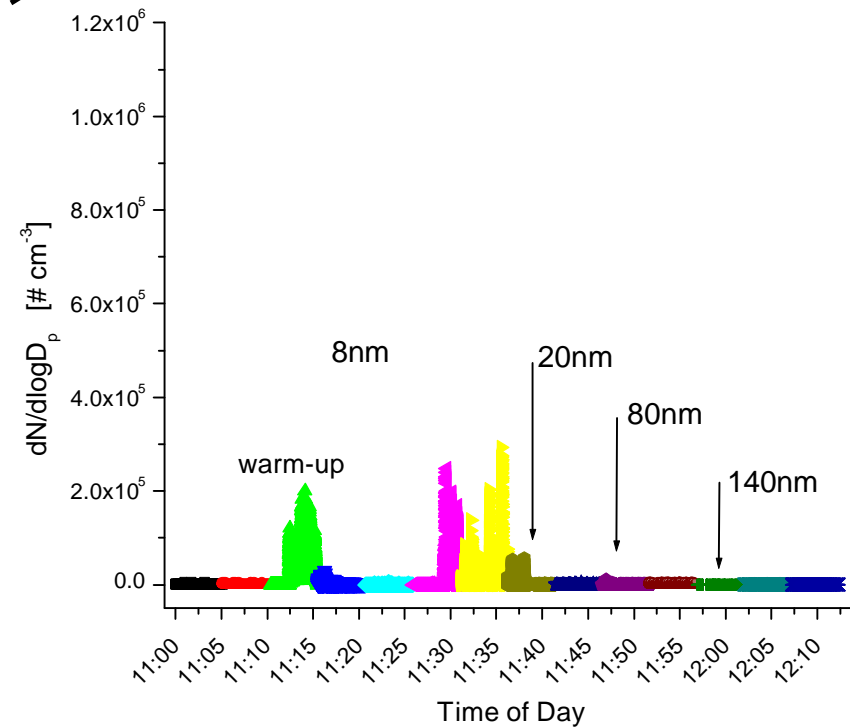
Individual Diameter Traces - CVS - CBD Tests

SIZE-FILTERED MODE

CNG re-test



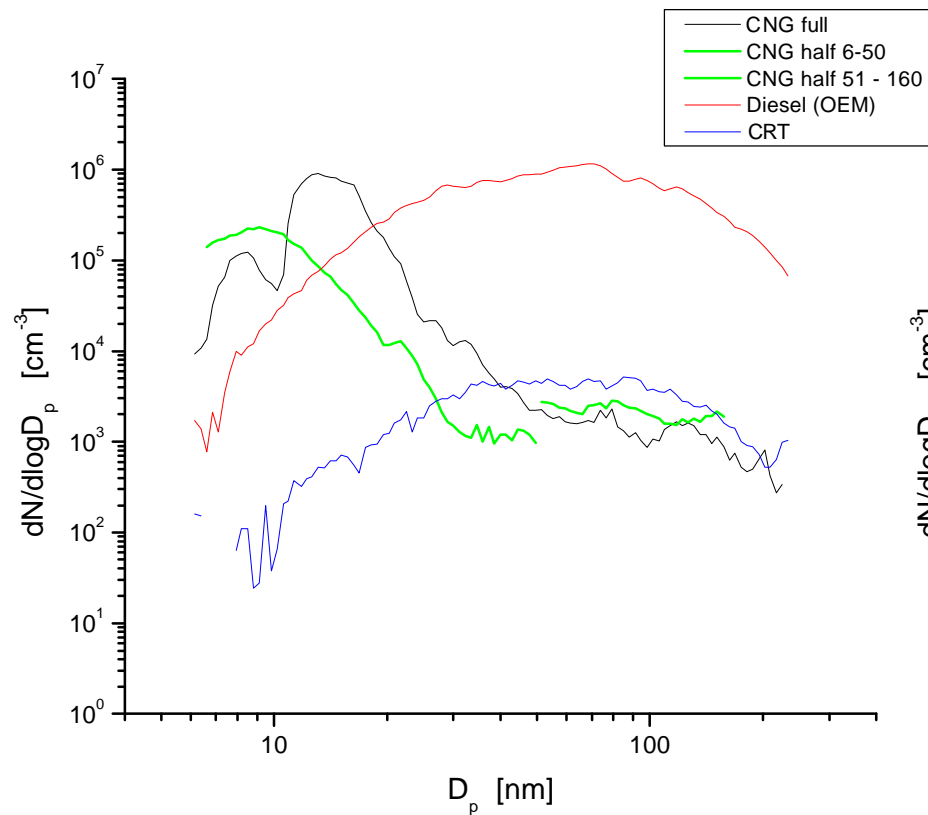
CNG



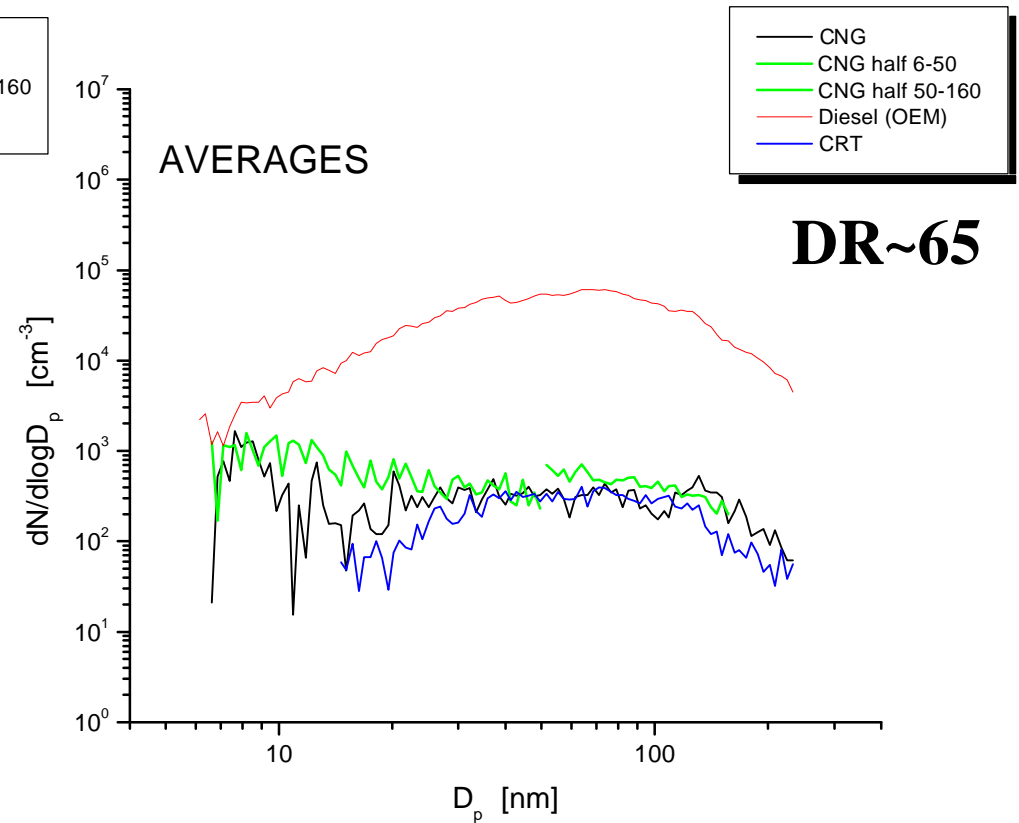
Average of Individual Scans - Dilution Comparison - CBD Tests

SIZE-SCAN MODE

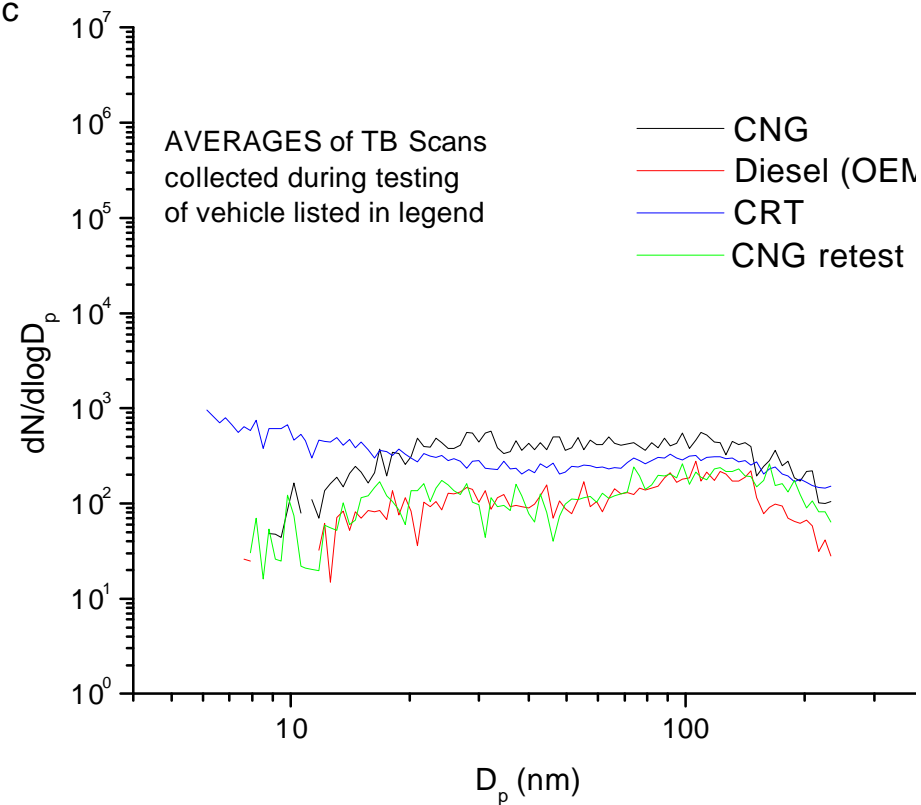
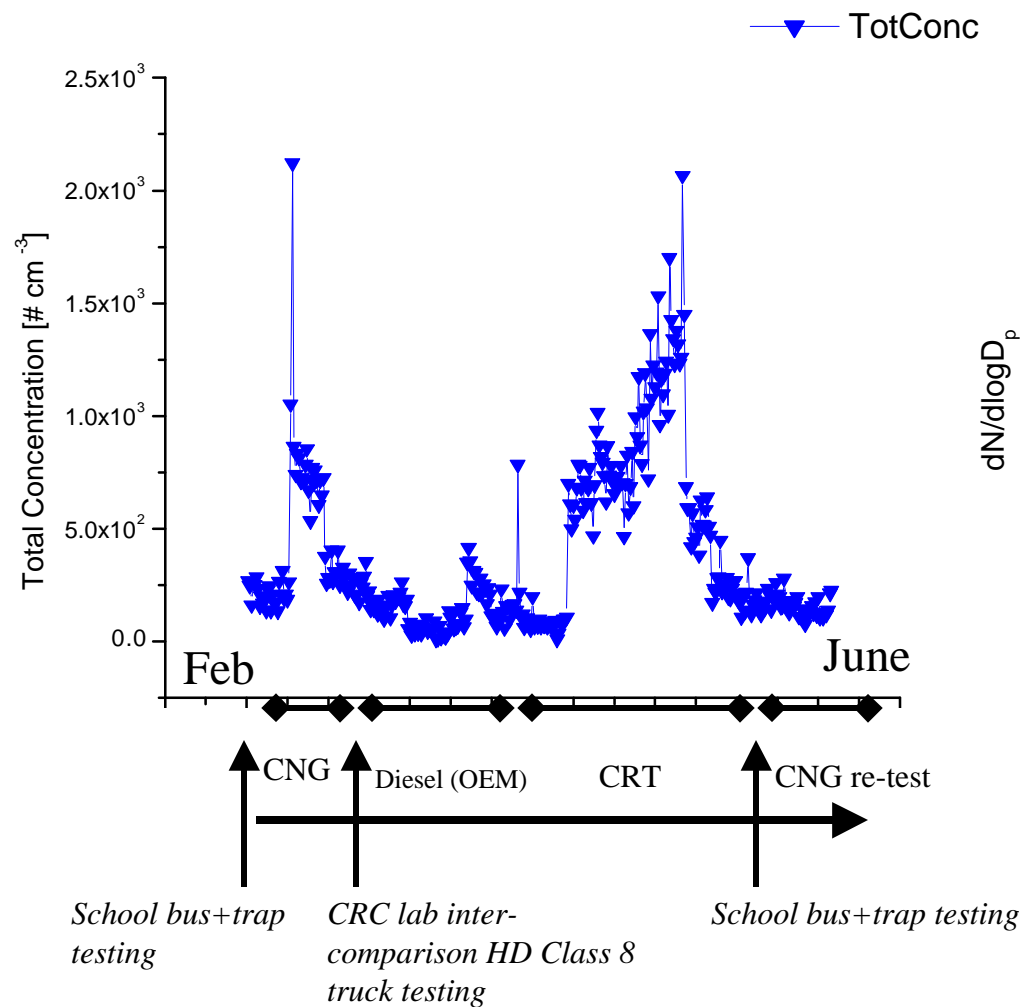
CVS



Mini-diluter



CVS Tunnel Blanks



Remarks for Regulated Emissions over CBD

- CRT showed reductions in CO (87%), THC (100%), and raw/uncorrected PM (88%) relative to Diesel (OEM)
- CRT and Diesel OEM NO_x not significantly different
- Significantly different NO₂/NO_x ratios in CRT (50%) and Diesel OEM (3%)
- Raw/uncorrected PM for CNG and CNG re-test showed reduction of 66 to 72%, respectively, relative to Diesel (OEM)
- CNG NO_x exhibited high variability. CNG re-test NO_x was 75% of Diesel (OEM) NO_x
- Because of composition of PM from CRT and role/magnitude of tunnel background, we may define “MINIMUM” reduction efficiency for PM traps if current sampling methods continue to be used

Remarks for Ultrafine Particles

- CRT showed reduction in particle counts for all particles in measured range for SS tests
- Only accumulation mode was evident in diesel for SS tests
- For SS, modes in CNG size distributions were not distinct, but nanoparticle (<50nm) concentrations were higher than for CRT
- Transient and cold-start resulted in highest numbers of ultrafines for all vehicles
- For SS, total counts for CNG and CRT were equivalent and lower than baseline

Remarks for Ultrafine Particles (cont'd)

- For CBD, CNG nanoparticles were smaller and more numerous than for baseline and CRT
- For CBD, CNG re-test resulted in highest 8 nm and 20 nm nanoparticle concentrations. Observed increase in THC's may explain
- Vehicle conditioning/tunnel artifacts play role when measuring CVS ultrafine concentrations for low emission vehicles
- Relative size distributions appear to be preserved between CVS and mini-diluter systems for 3 vehicle types examined